INVESTIGATION OF PHYSICAL PROCESSES IN THE UPPER ARCTIC OCEAN

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LONG TERM GOALS

Much of our understanding of the Arctic Ocean and its interactions with climate is well founded conceptually and has been reproduced in numerical models. The observational basis remains, however, inadequate to identify critical processes and geographical regions, to quantify the parameters used in models, or to verify many aspects of the model results. The primary goal of this program has been to improve our understanding of the roles of small-scale and mesoscale processes within the Arctic Ocean system through participation in field activities and analyses of the resulting data. A secondary goal has been to provide modelers with information suitable for improved parameterization and validation.

OBJECTIVES

Specific objectives contributing to this goal have included:

(1) Describe upper layer physical oceanographic conditions in the Arctic Ocean with the geographical emphasis on the Eurasian Basin and topical emphases on small-scale and mesoscale features.
(2) Assess the influence, through estimation of the spatial distributions of mean and internal wave shear and their influence on mixing, on the Arctic Warm Water layer of vertical mixing associated with the peripheral slope boundary currents.
(3) Assess, through description and physical reasoning, possible influences of mesoscale features such as fronts and eddies on the horizontal transfer of heat and dissolved material from the peripheral slope currents to the interior basins.
(4) Improve, through integration of the above and through collaboration with researchers who are carrying out concurrent tracer analyses of the Arctic Ocean, processes and rates by which the central Arctic Ocean basins are ventilated.

APPROACH

This project uses a field-based approach. Suitable data are obtained on an opportunity basis during participation in field activities which have been devoted primarily to support of other programs. Analyses of these data take advantage of published theory and methods, especially, those relating to turbulent mixing and double diffusive processes. Contacts are initiated as appropriate with theoretical and laboratory-based research personnel in order to maintain close contact with the state of the art. Interaction with modellers is being maintained primarily via a working relationship with the modelling group at the Naval Postgraduate School in Monterey.

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ACCOMPLISHMENTS

Analyses have continued of the temperature (T), salinity (S) and vertical current profile data obtained during summer 1993 and 1995 cruises of the German research icebreaker *Polarstern*. Results have been presented at a number of venues and are being submitted as two separate papers in the Journal of Marine Systems Proceedings Volume for the 29th International Liège Colloquium on Marine Hydrodynamics (see appended Statistical Information).

The past year has seen acquisition of an extensive dataset from a summer 1996 cruise of the *Polarstern*. The Principal Investigator on this program participated in the cruise with funding from another project, acquiring during this participation vertical profiles of T and S as well as vertical current profiles from a hull-mounted 150-kHz acoustic doppler current profiler (adcp). These data are presently being analyzed, and preliminary results will be presented at the WMO/ICSU/IOC WCRP conference on Polar Processes and Global Climate which is taking place in early November on Orcas Island, Washington.

Finally, three deep ocean moorings were recovered from the vicinity of the Lomonosov Ridge in summer 1996. These moorings recorded year-long records of T, S and currents throughout the water column and can be expected to contribute to our understanding of mesoscale features in the region. Analyses of these data are as yet preliminary.

SCIENTIFIC/TECHNICAL RESULTS

Remote from the relatively weak peripheral boundary currents and isolated from the upper mixed layer by a permanent halocline, the central Arctic basins comprise a low energy regime. The upper ocean below the mixed layer and above about 800 m has been seen in the 1993, 1995 and 1996 field data to be unstable to double diffusion. Deeper strata are generally stable except for isolated instances where intrusions of Barents Sea water contribute to finger instabilities. These data, as well as other oceanographic data obtained from the central Arctic over the past decade, have revealed staircase features and inversions throughout these depths and in various parts of the Arctic Basin that are consistent with double diffusion. Explanations have invoked formation of inversions that are subsequently modified or propagated by way of double diffusive processes. Inversions appear to form in the Arctic Ocean through isopycnal interleaving at fronts, such as those present where the Barents Sea outflow enters the Arctic Ocean or where Eurasian Basin waters abut the relatively cold waters of the Canadian Basin in the vicinity of the Lomonosov Ridge. Additional formation regions might occur where dense plumes, observed in the 1993 data, enter from the peripheral shelf seas. During summer 1996 the research vessel *Polarstern* completed an oceanographic transect extending for more than 900 km across the central Arctic Ocean, spanning the Nansen and Amundsen basins and entering the Makarov Basin. Data obtained along this transect revealed steplike vertical temperature and salinity inversions having vertical scales up to as large as 100 m and that were coherent over horizontal scales exceeding 500 km (figure 1). These features traversed water masses that were known based on tracer analyses to have ages differing by several years. They superficially resembled features that have been previously observed at other locations in the Arctic Ocean and that have been attributed to double diffusion. They were absent from the waters of the peripheral currents along the Siberian continental slopes and along the Lomonosov Ridge. Inversions found along the Ridge were of a different character and appeared to have a different origin. The inversions are consistent with formation along both narrow and broad frontal regions within the eastern Arctic Ocean followed by advection with the peripheral slope currents.

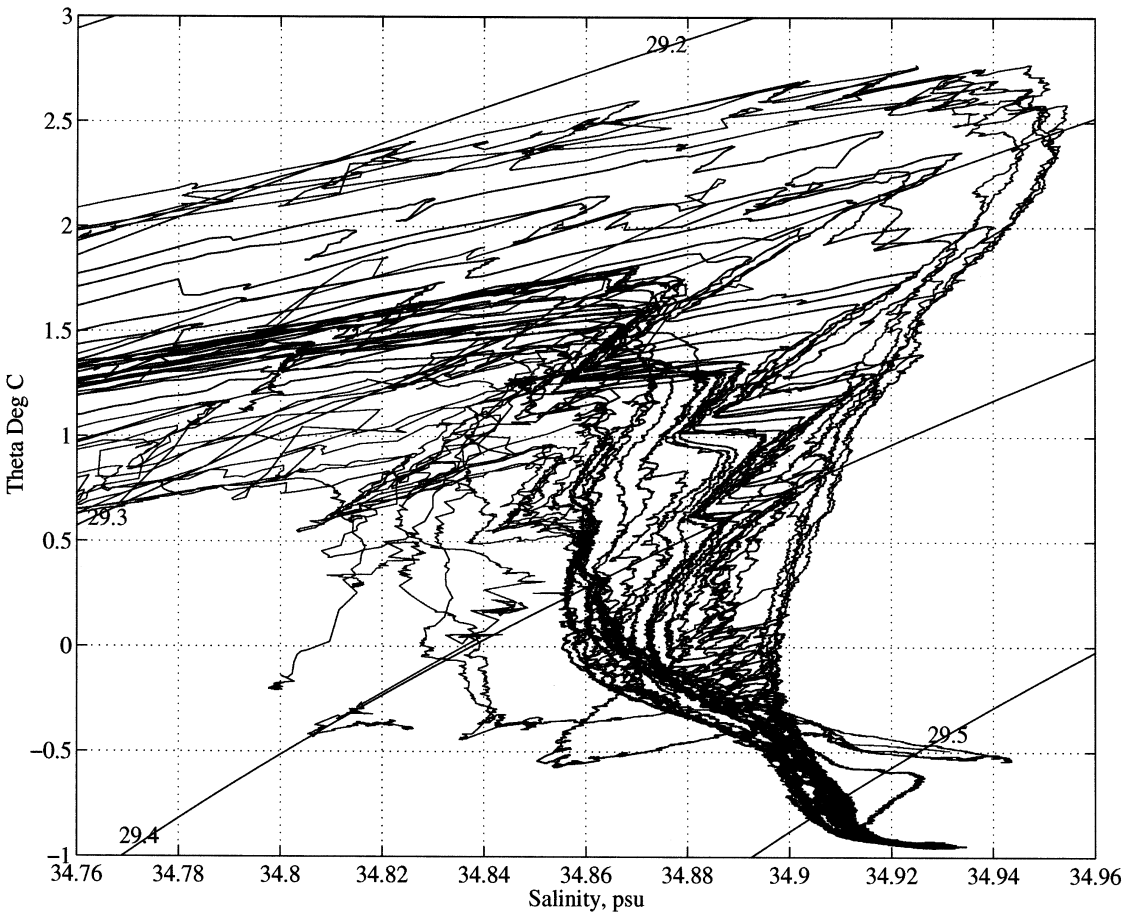

Figure 1. Preliminary temperature-salinity (T-S) curves for stations along the summer 1996 Polarstern transect that extended from the Kara Sea shelf break across the central Eurasian Basin to the Makarov Basin of the Arctic Ocean. Large double-diffusive inversions are seen as the sharply defined, spatially coherent "sawtooth" features. Curves from near the southwestern source region for Atlantic Water are on the upper right, whereas curves for the oldest water, in the Makarov Basin, are near the center of the figure. The irregular curves approaching lower left represent inflowing shelf water from the Barents and Kara seas. The individual steps in T-S space are slightly inclined relative to the isopycnals (shown here as lines of equal $\sigma_{0.5}$), indicating slight density increase as they propagate from a presumed source in the strong frontal regions off the Kara and northwestern Laptev seas.

This picture of a relatively low energy environment breaks down near the eastern Arctic continental shelves. Vertical profiles of currents were measured, along with temperature and salinity, at many sites in the Kara and Laptev seas during the summers of 1993, 1995 and 1996. These measurement sites extended from the shelves out into the deep basins. The eastern shelves are characterized, because of their great breadths and shallow depths, by strong tidal currents. Additionally, the slope regions are overlain by the highest subsurface core temperatures found in the Arctic Ocean. These two factors predispose the region to potentially large heat fluxes out of the warm core, making it one of the more important regions of the Arctic Ocean for warm core modification. We have computed upward heat fluxes from the warm core using the measured

vertical profiles of T, S and horizontal currents from selected stations occupied during 1993 and 1995 from the Polarstern (Figure 2). The results show elevated upward heat fluxes associated with the slope regions where tidal shear and large vertical T gradients associated with the warm core combine, leading to fluxes that exceed 100 Wm^{-2} in the especially energetic western Laptev Sea.

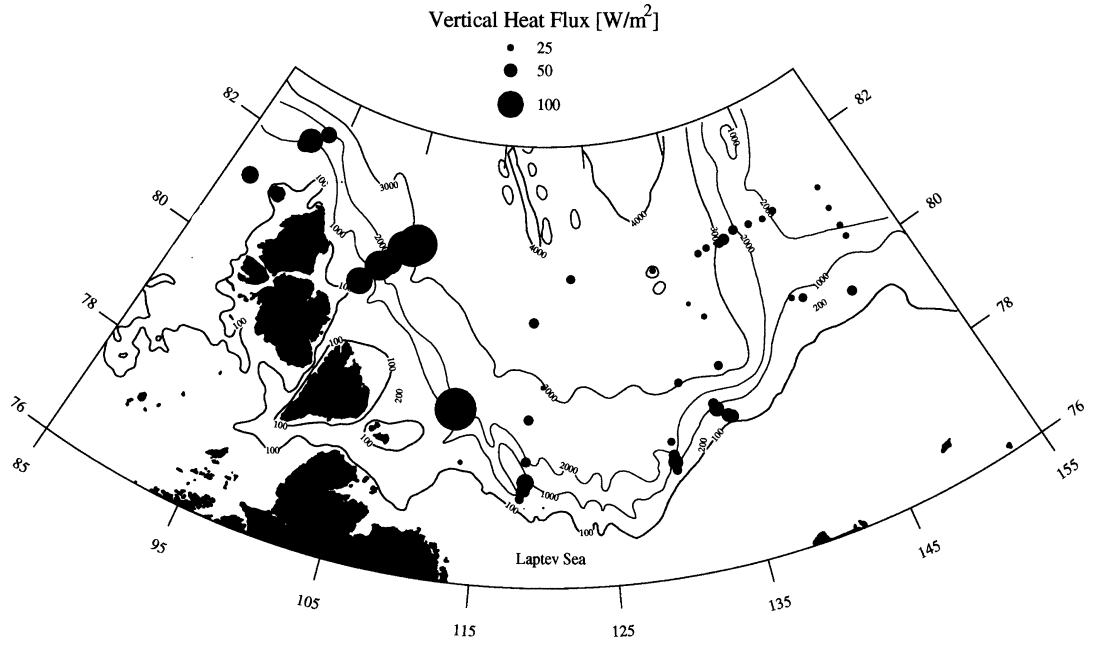

Figure 2. Upward heat fluxes through the 100-200 m depth layer computed using T, S and current profile data obtained during the 1993 and 1995 Polarstern cruises. Bottom contours are labled in meters.

The objective of assessing mesoscale eddies has been only partially met. Features that appeared to be eddies were detected in all three of the *Polarstern* cruises. The wide station spacing, which was typically of order one internal deformation radius or greater, allowed only detection but precluded reasonable estimates of size and other properties. It is interesting to note, however, that eddies were found at depths from the halocline down to about 1200 m, and at various locations including the deep basins remote from the boundaries. Apparent eddies contained in the boundary currents were consistent with formation in the strong frontal region north of the Kara Sea. Analyses of the boundary current eddies will continue, utilizing the current measurements from the Lomonosov Ridge moorings.

IMPACT FOR SCIENCE (and/or) **SYSTEMS APPLICATIONS**

Results of this research deal with the upper ocean heat balance and bear directly upon climatological considerations inasmuch as they impact sea ice cover and the maximum T in the

warm Atlantic Water layer. The double diffusive phenomena are of basic theoretical interest due to their uniquely great spatial extent and continuity over interannual periods.

TRANSITIONS

Basic results concerning double diffusive processes and comparisons among field and model results are expected to have wide application outside the Arctic. The Arctic Ocean comprises, because of the apparently very low level of turbulence in the interior basins, an ideal regime within which to study double diffusive processes. Basin-wide conditions vary from the well-defined and energetic frontal system north of the Kara and northwestern Laptev seas to the nearly uniform fields in the basin interiors. It should be possible to examine processes ranging from initial formation through evolution to final dissolution of double-diffusive features, thereby adding sorely needed oceanic-scale information to that presently available from laboratory model studies.

RELATED PROJECTS

The Principal Investigator on this program participated in two related projects during FY1997. One, funded by ONR, was titled "Submarine-based acoustic doppler current profiler (adcp) measurements of the Arctic Ocean upper halocline, including rider provision for summer 1997 SCICEX cruise". This project is at present obtaining upper layer current profiles from an upward-looking adcp mounted atop a submarine hull. These current data will be used, along with T , S and water chemistry data obtained from the submarine by other investigators, to further assess upper layer shear and mixing processes in the upper Arctic Ocean and to expand the geographical and temporal coverage of our database. A second project, funded through ONR by the Arctic Nuclear Waste Assessment Program (ANWAP) and titled "Radionuclide transport pathways in the eastern Arctic Ocean", has provided funds during FY97 for ongoing analyses of T, S and current data obtained during 1993, 1995 and 1996 cruises of the *Polarstern* to the Arctic Ocean. The ANWAP project is concerned primarily with regional advective transports and with dispersion of possible waste materials. Consideration of mesoscale and smaller-scale processes is nonetheless necessary in order to explain aspects of the regional circulation and to quantify dispersion.

PUBLICATIONS

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